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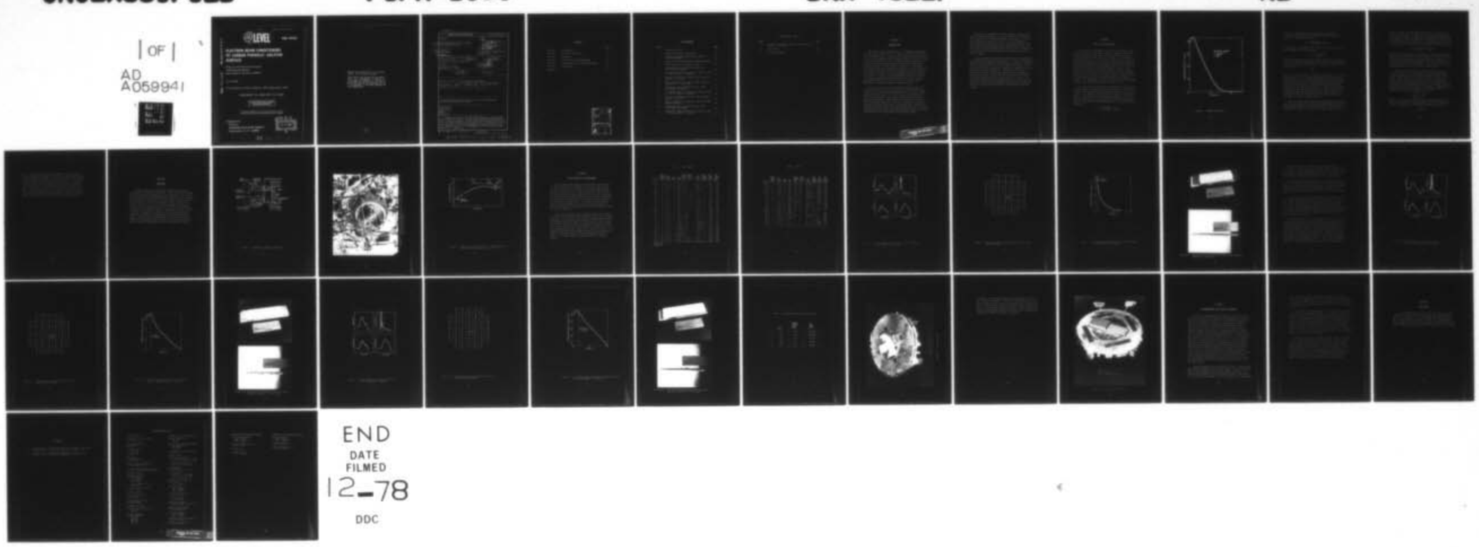

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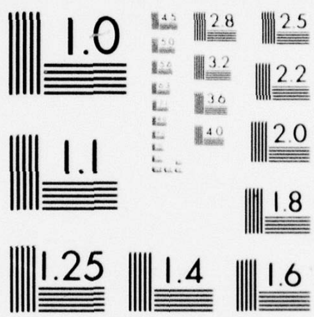

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ELECTRON BEAM CONDITIONING OF CARBON PHENOLIC ABLATOR SURFACE

Physics International Company
2700 Merced Street
San Leandro, California 94577

June 1978

Final Report for Period March 1977—December 1977

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Hardware and techniques have been demonstrated that allow controlled depths of phenolic removal from a tape-wrap carbon phenolic ablator material using a pulsed electron beam. Phenolic removal depths ranged from 5 mils to 15 mils with good uniformity over the sample area. Calculations based on the above experimental results indicate that with an optimized system, single pulse irradiation areas of up to 1000 cm^2 are possible on the Physics International OWL II' generator.

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ILLUSTRATIONS

ILLUSTRATIONS (cont.)

SECTION 1

INTRODUCTION

The goals of this program were (1) to develop and demonstrate techniques and hardware that are capable of producing controlled electron deposition in a tape-wrap carbon phenolic ablator material so as to obtain phenolic removal depths between 0.1 mm and 0.04 mm (5 mils and 15 mils) and (2) to establish a data base that could be used to design an optimized system to maximize single-pulse irradiation areas for these beam environments. To accomplish these goals, a series of experiments, based on electron deposition code and electron-beam generator calculations, were carried out on the OWL II generator using existing diode and magnet hardware (Reference 1). Results of these experiments indicate that with an optimized system the OWL generator can be used to irradiate areas between 680 cm^2 to over 1000 cm^2 with a single pulse, depending on the depth of phenolic removal required.

An initial set of energy deposition calculations was performed to determine the most appropriate voltage and mean angle of incidence of the electron beam necessary to achieve specified phenolic removal depths of 0.13 mm (5 mils), 0.25 mm (10 mils) and 0.38 mm (15 mils). Once the most appropriate voltage and angle were determined, these numbers were then used to calculate the corresponding generator, diode, and experimental parameters required to produce these beams. The experimental variables were the generator pulse charge, the anode-cathode separation, electron scattering foil thickness, and beam compression ratio. The cathode area (410 cm^2) was fixed based on the existing hardware.

Three sets of parameters have been identified analytically and confirmed experimentally that will uniformly and repeatably remove phenolic to the required depths listed above. At each of these conditions at least five each 5 cm x 20 cm samples of carbon phenolic ablator material were irradiated, plus at least three calorimeter shots were taken to measure beam fluence and uniformity. The test specimens were flat sections of a tape wrap carbon phenolic that were provided by the Lockheed Space and Missile Company.

Phenolic removal was measured by measuring the thickness of the sample before and after irradiation. A series of such measurements was used to determine the uniformity of removal. The major source of uncertainty in the removal depth is the state of the base material after irradiation. Although it appears to be intact, there may be internal microscopic cracks due to the thermo-mechanical stresses. Such cracks would make the base material appear thicker after irradiation and thereby make the removal depth appear smaller than the actual value. In any case, the results of this investigation demonstrate that, given a specific technique for measuring the phenolic removal depth, the desired amount of removal can be obtained in a uniform and repeatable fashion.

SECTION 2

PRE-TEST CALCULATIONS

The initial pre-test Monte Carlo electron transport calculations (Reference 2) obtained a series of deposition profiles for beam energies between 350 and 700 kV with mean angles of incidence between 30 and 60 degrees. Figure 1 is an example of a deposition profile. One criterion that was used to select the experimental conditions was to choose a deposition profile where the required removal depth was located on the steeply descending portion of that profile. This minimizes the effect of any variations in beam fluence upon the depth of removal. Another criterion was to select a deposition profile such that changes on the order of 10 degrees in the mean angle of incidence of the electrons would result in very small changes in the depth of removal. The combination of these two criteria puts the maximum sensitivity of the removal depth on the beam voltage.

The selected deposition profile determines the diode voltage and mean angle of incidence of the electron beam. The diode voltage can be related to the generator parameters in the following way. The OWL generator is capable of two basic operational modes. In the OWL II mode, the generator impedance is 1.9 ohm; the tube voltage (V_T) is related to the machine pulse charge voltage (V_{pc}) while the load impedance (Z_L) is, by the following equation,

$$V_T = \frac{0.68\ V_{pc}\ Z_L}{1.9 + Z_L} \quad \text{(OWL II)}$$

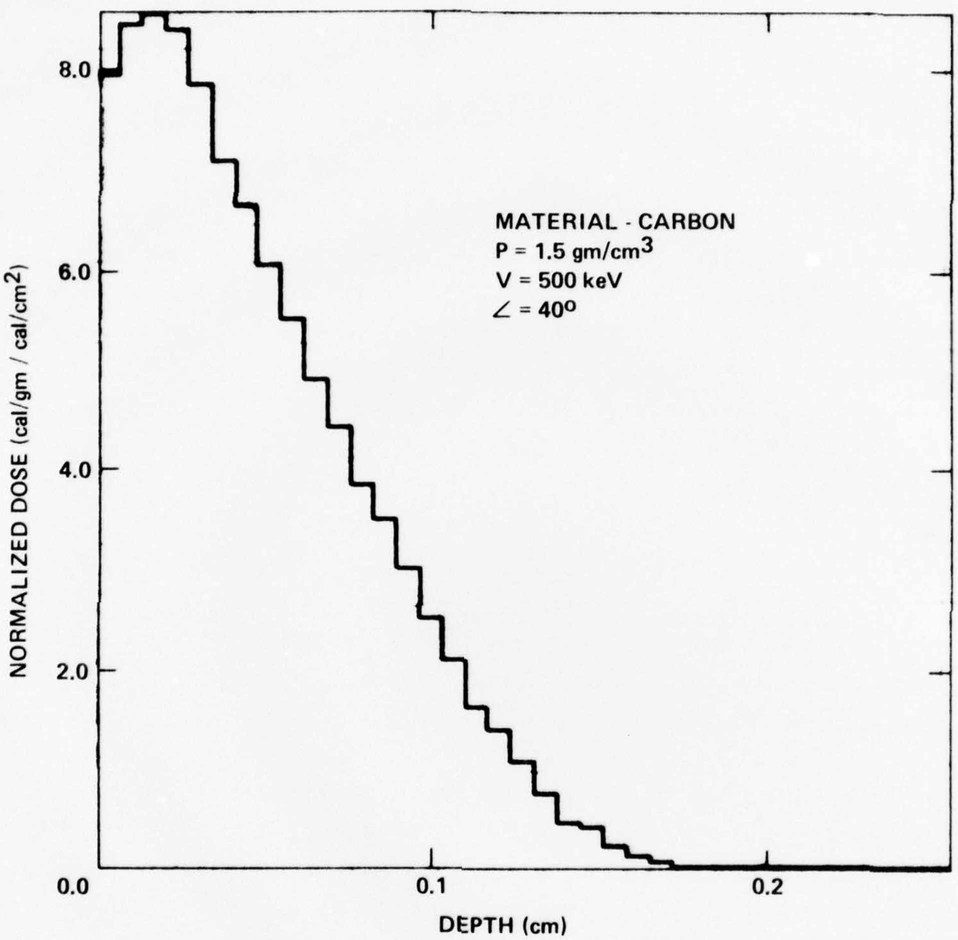

Figure 1 Deposition profile.

The OWL II' modification drops the generator impedance to 1.1 ohm by adding an extra transformer stage. The relevant equation for this modification is

$$V_T = \frac{0.49\ V_{pc}\ Z_L}{1.1 + Z_L}\ \text{(OWL II')}$$

In both cases, the impedance of the diode Z_L (in ohms) is given by the Langmuir-Child relationship.

$$Z_L = \frac{4.27 \times 10^5\ D^2}{A\ V_T^{1/2}}$$

where A is the diode area in centimeters squared, D is the anode-cathode separation in centimeters, and V_T is the tube voltage in volts. The measured tube voltage is actually the sum of the diode voltage and

$$L \frac{dI}{dt}$$

where L is the inductance of the diode feed section. For a given geometry the L term is constant which makes the diode voltage proportional to V_T. In these experiments the mean diode voltage, the basis of the Monte Carlo deposition profiles, was between 45 percent and 50 percent of the peak measured tube voltage. Somewhat greater beam energy output can be obtained at low diode voltages with the OWL II' configuration. However, because the existing hardware was compatible with the OWL II diode, all experiments described in this report were carried out with the generator in the OWL II configuration.

Once the pulse charge voltage and anode-cathode spacing have been set, calculations are used to determine whether the electron beam must be expanded or compressed in order to deliver the appropriate fluence to the target. An axial magnetic field is used to transport the beam from the diode to the target and may also be used to modify the beam area. A nominal threshold dose of 0.8 MGy (200 cal/g) is required to remove phenolic and by using this number in conjunction with the calculated deposition profile, the required fluence is determined. At the anode plane the fluence (ϕ) for a 100 ns pulse is given by the Langmuir Child formulation

$$\phi = \frac{2.4 \times 10^{-12} V^{5/2}}{D^2} \; (kJ/m^2)$$

where V is the diode voltage in volts and D is the anode-cathode separation in centimeters. If the fluence at the anode plane is less than the required value, the beam must be compressed. If it is greater, the beam may be expanded. In order to achieve the fluences called for in this program, it was necessary to compress the beam to some extent for all three removal depths.

To obtain the mean angle of incidence called for by the deposition profile, it is possible to increase the mean angle, by adding scattering foils (filters) between the diode and the target. Since the anode foil itself consists of 0.0025 cm of titanium, some scattering will occur here giving the beam an average angle of approximately 30 degrees at a voltage of 500 kV. The electron angles in the beam will vary with the magnetic field strength, and hence the beam area. For adiabatic compression or expansion of the beam, the angles will vary as

$$\frac{\sin^2 \theta_i}{\sin^2 \theta_f} = \frac{A_f}{A_i}$$

where θ_i, θ_f, A_i and A_f are the initial and final angles and areas, respectively. If greater angles are required, additional filters are indicated. The required thickness is given by

$$\theta = \frac{20}{\gamma} d^{\frac{1}{2}}$$

where θ is the scattering angle in radians, d is the titanium filter thickness in centimeters, and γ is the normal relativistic constant for the electrons, i.e., the ratio of the total electron energy (including its rest mass) to its rest mass. In addition to introducing a mean scattering angle, the filter also lowers the kinetic energy of the electrons. This effect can be on the order of 100 keV for a 0.0025 cm titanium filter. Because of this, it may be necessary in some instances to iterate the above procedure by increasing the diode voltage in order to achieve the desired deposition profile on the far side of the filter foil.

SECTION 3

APPARATUS

The OWL II generator was used for these tests and most of the hardware was already in existence. A 410^2 cm circular cathode was used during the experiments that were performed to verify the predicted phenolic removal depths and to provide a set of specimens for evaluation. Three magnet coils were used to apply the longitudinal magnetic fields for beam control; these coils could be moved in space to create several different magnetic geometries. A diagram of the apparatus is shown in Figure 2 and a picture of the apparatus is shown in Figure 3. The magnetic field is plotted in Figure 4. Electrons are emitted from the cathode and pass through the transmitting titanium anode and scattering foils (if used). The beam is then compressed by the magnetic field and impinges on the sample which is placed so as to have the desired amount of magnetic compression to yield the calculated fluence.

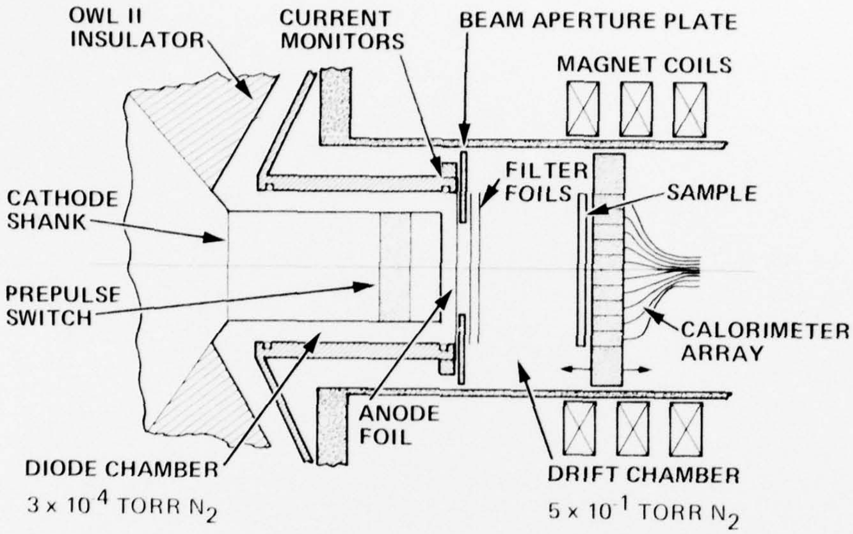

Figure 2 Schematic of ablator experiment.

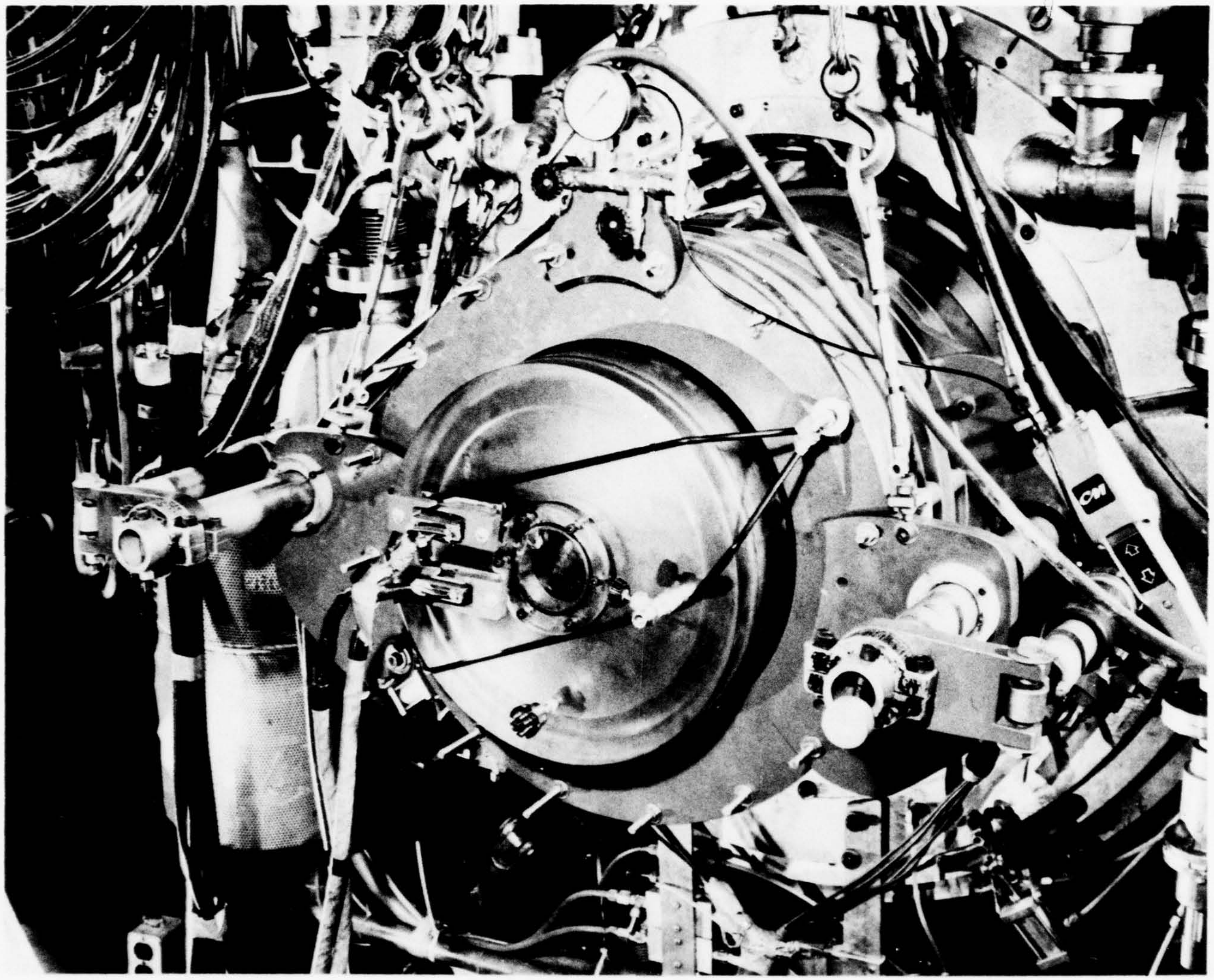

Figure 3 Ablator experiment showing target chamber and magnet hardware.

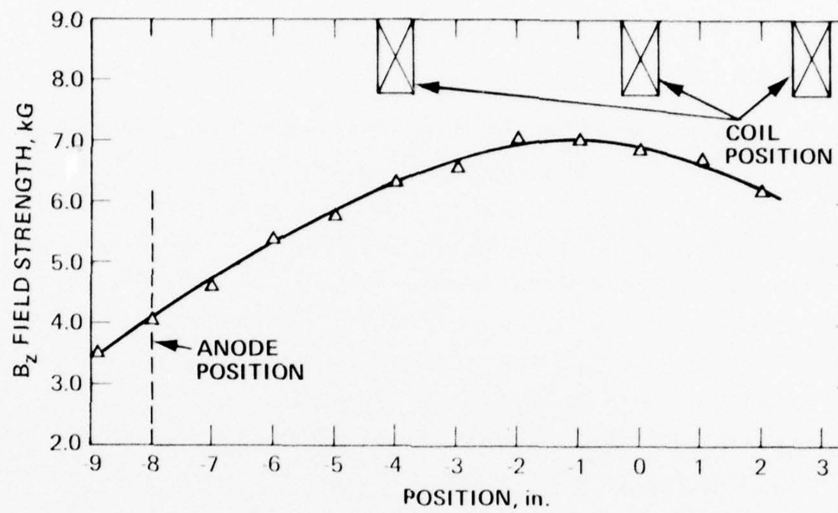

Figure 4 Measured Bz field strengths for magnet hardware. Capacitor bank charging voltage = 8 kV.

SECTION 4

DESCRIPTION OF THE EXPERIMENT

This program established three experimental conditions of the OWL II generator for removal of 0.13, 0.25, and 0.38 mm (5, 10, and 15 mils) of phenolic from the tape-wrapped carbon phenolic ablator material. Table 1 presents a record of all data taken during this experimental series of tests. The depth of removal was established by measuring the material thickness before and after irradiation; the difference was then defined as the phenolic removal depth. It should be noted, however, that there are possible errors in this technique because of cracks and thermal stresses that may exist in the material remaining after irradiation.

The 0.13-mm condition uses a machine pulse charge voltage of 2.1 MeV with an anode/cathode spacing of 8 mm, giving a diode impedance of 0.8 ohm and a mean voltage of approximately 360 kV. The beam was passed through a 0.025-mm-titanium filter and then compressed in area by a factor of two giving an average fluence of 0.50 to 0.55 MJ/cm^2 (12 to 13 cal/cm^2). Typical diode electrical parameters for this condition are shown in Figure 5. The measured calorimeter map is shown in Figure 6 with a deposition profile calculated from the electrical parameters shown in Figure 7. A typical sample of ablator material is shown in Figure 8.

Table 1 Shot Summary

Shot No.	Anode-Cathode Spacing (mm)	Pulse Charge (Mv)	Sample Panel	Shot Type	Phenolic Removal Depth (mils)	Titanium Filter Thickness (mils)	Fiber Length (mils)	Anode Target Separation (inches)	Peak Tube Voltage (kV)	Peak Diode Current (kA)
4095	8	2.73	A	Cal.	12		110	3	924	578
96	11	2.55	A	Cal.	14		130	3	940	488
97	9	2.55	A	Cal.	10		130	6		525
98	9	2.55	B	Sam.	10		90-100	6	898	566
99	13	2.37	A	Cal.	22	.5	120	7	1040	410
4100	8	2.1	A	Cal.	4-5	1.0	40	7	792	512
01	8	-	A	Sam.	2-3	2.0		7	825	512
02	8	2.2	A	Sam.	4-5	1.0	50-80	7	851	512
03	8	2.2	A	Cal.		1.0		7	838	512
04	8	2.3	A	Sam.	5-7	1.0	50-60	7	1046	603
05	8	2.1	B	Sam.	4	1.0	30-50	7	743	471
06	8	2.2	B	Sam.	4-5	1.0	50-70	7	881	525
07	8	2.2	A	Cal.	5	1.0	40	7	815	517
08	8	2.2	B	Sam.	5	1.0	50-60	7	869	544
09	9	2.65	B	Cal.	16		170	6	1088	578
4110	9	2.55	B	Cal.	10-12		130	6	1154	554
11	9	2.55	B	Sam.	10		80-110	6	980	551
12	9	2.55	B	Cal.	10-12		80	6	924	537
13	9	2.73	B	Sam.	5-12		80-110	6	1099	554
14	9	2.55	A	Cal.	10		90	6	875	512
15	9	2.46	C	Sam.	9-11		100-120	6	937	520
16	9	2.55	C	Sam.	9-10		100-110	6	1087	520
17	9	2.55	C	Sam.	9-10		100-130	6	924	551
18	9	2.37	B	A.S.*	7-15		40-120	6	917	500
19	9	2.37	C	OL.**	10		60-70	6	826	488
4120	9	2.37	C	OL.**	10		60-80	6	898	488
21	9	2.2	B	6-strps.				6	891	464
22	11	2.64	A	Cal.	20		150	3	1020	439
23	11	2.64	A	Cal.	20		130	3	957	439
24	11	2.55	A	Cal.	15-17	0.5	120	3	980	447
25	11	-	C	Sam.	17-19	0.5	90-100	3	921	439

* Angle Shot

** Overlay

Table 1 (cont.)

Shot No.	Anode-Cathode Spacing (mm)	Pulse Charge (Mv)	Sample Panel	Shot Type	Phenolic Removal Depth (mils)	Titanium Filter Thickness (mils)	Fiber Length (mils)	Anode-Target Separation (inches)	Peak Tube Voltage (kA)	Peak Diode Current (kV)
4126	11	2.4	C	Sam.	9-12	0.5	60-80	3	836	432
27	11	3.01	A	Cal.	20	0.5	130-150	3	1149	512
28	11	2.37	A	Cal.	15-16	0.5	150	3	941	415
29	11	2.46	A	Cal.	15	0.5	110	3	1008	407
4130	11	2.46	C	Sam.	7-10	0.5	80-100	3	948	447
31	9	2.55	A	Cal.	15	-	180-200	3	907	527
32	9	2.55	D	Sam.	14-15	-	100-130	3	980	542
33	9	2.70	D	Sam.	7-15	-	100-130	3	940	554
34	9		D	Stencil		-	110	3	977	537
35	9	2.55	D	Sam.	10-12	-		3	916	483
36	7	2.55	D	Sam.	7-12	-	80-100	3	890	610
37	7	3.10	D	Cal.	15	-	120	3		586
38	7	3.10	D	Sam.	13	-	120-130	3		659
39	7	2.00	D	Sam.				3	705	293
4140	7	3.00	A	Cal.	15	-	130	3		
41	7	3.00	D	Stencil		-		3		634
42	7	3.00	C	Sam.	15	-	80-120	3		615
43	7	3.01	C	Sam.	15	-	90-120	3		683
44	7	3.01	C	Stencil		-		3		683
45	7	3.10	C	"		-		3	736	659
46	7	3.10	C	"		-		3	825	732
47	7	3.10	C	Sam.		-	80-170	3	848	720

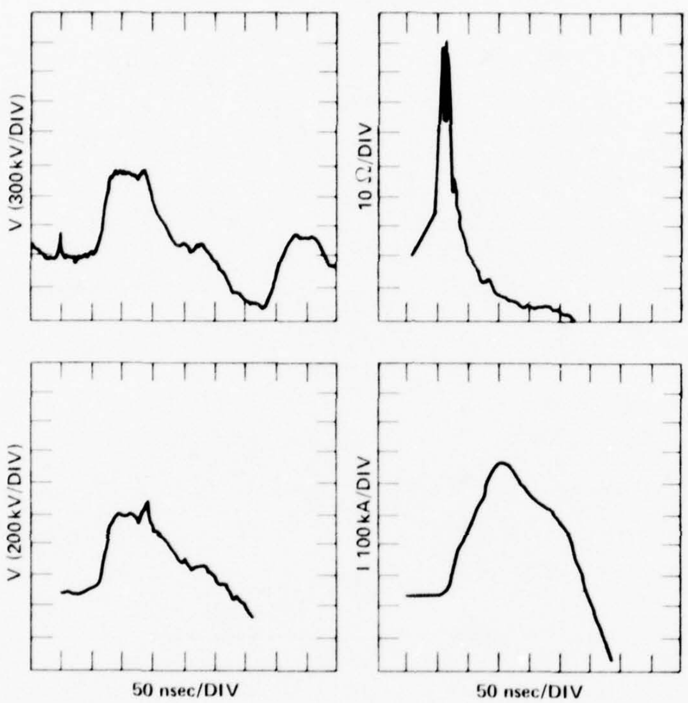

Figure 5 Diode diagnostics for Shot No. 4100. Phenolic removal depth = 0.005 inch.

	X	17	–	9	
12	15	15	14	14	11
X	12	10	14	13	15
15	12	12	SAMPLE BLOCK	X	15
12	13	13	15	16	13
	X	17	15	12	

Figure 6 Calorimeter data (cal/cm^2) Shot No. 4100; 5-mil-phenolic removal.

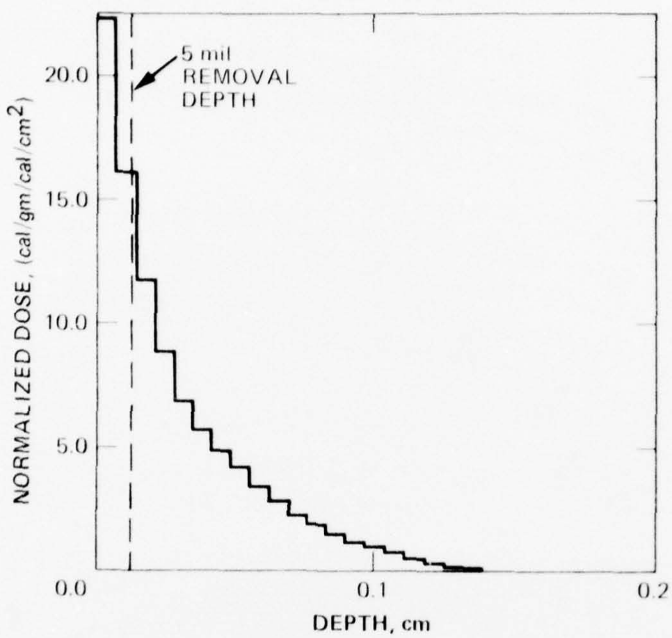

Figure 7 Calculated deposition profile for Shot No. 4100; V = 378 kV, angle = 60 degrees.

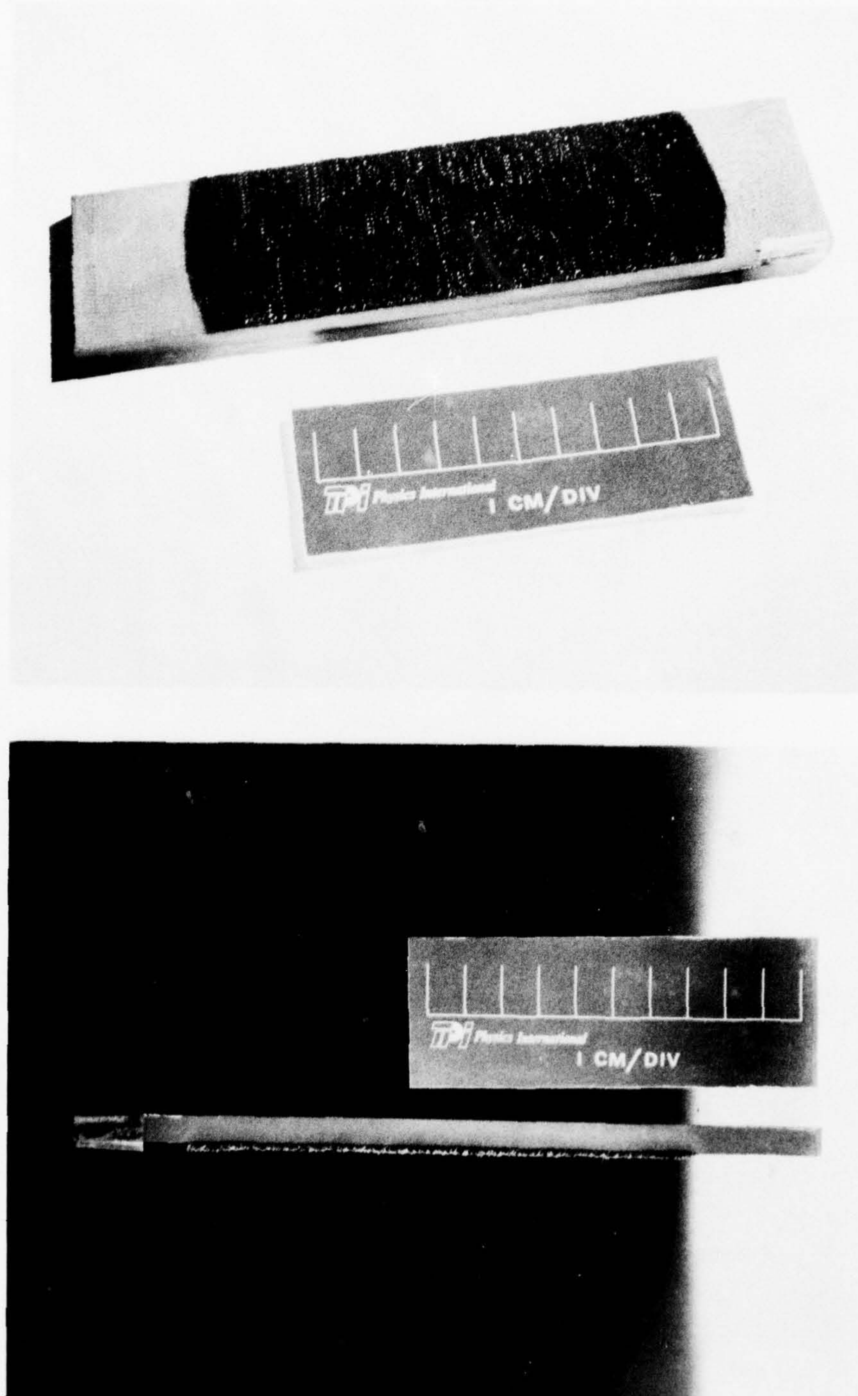

Figure 8 Top and side photos of Shot No. 4100; phenolic removal = 0.005 inch.

The 0.25-mm removal conditions used a pulse charge of 2.55 MeV with a 9-mm-anode/cathode spacing and 1.7:1 compression, an average fluence of approximately 1.7 MJ/m^2 (40 cal/cm^2), and a mean voltage of approximately 500 kV. Figures 9 through 12 give the experimental conditions and samples for 0.25-mm removal.

The 0.38-mm removal condition uses a 3.0-MeV pulse charge with a 7-mm anode/cathode spacing and a 1.4:1 magnetic compression. Figures 13 through 16 give the experimental parameters and sample photographs for a typical 0.38-mm removal. The anode for all three beam conditions consisted of a 0.013-mm (1/2 mil) titanium foil.

For each of the three above conditions, 3 calorimeter shots and 5 sample shots were taken to verify reliability. In the 0.13- and 0.25-mm removal, reliability was very high. However, the 0.38 mm condition required some care because the magnetic field being used was apparently marginal to reduce beam pinch and an occasional shot would be obtained with increased removal depth near the center of the beam. A higher strength magnetic field should avoid this difficulty.

Two other experiments of interest were performed: the first determined the effect of orientation angle of the material with respect to the beam axis; the second investigated the feasibility of minimizing the perturbations along the line between two adjacent irradiation areas on a single sample. Figure 17 shows a series of blocks mounted in the beam from perpendicular to the beam (normal irradiation conditions) to an angle of 60 degrees with respect to the beam axis. Table 2 is a record of the depth of removal for each of these blocks. It can be seen that the removal is relatively constant up to the angle of approximately

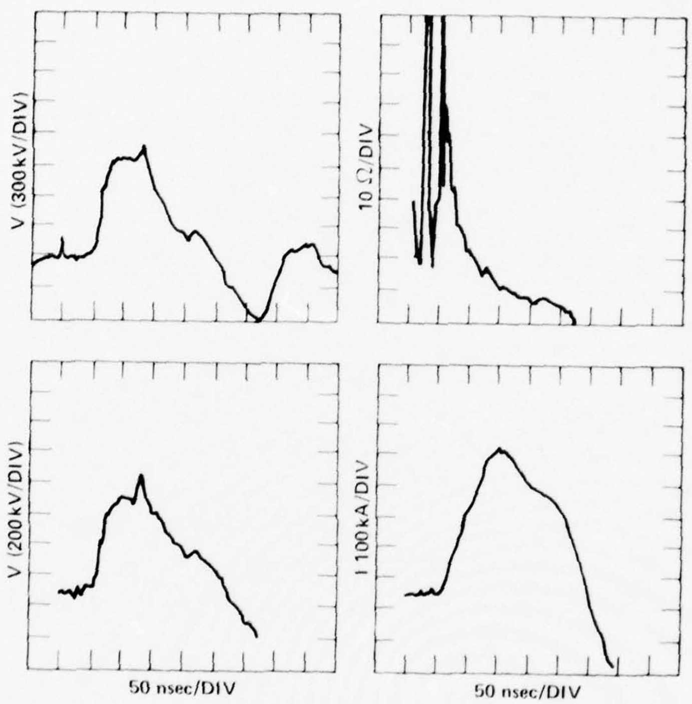

Figure 9   Diode diagnostics for Shot No. 4097; phenolic removal depth = 0.010 inch.

	X	31	X	26	
22	33	37	26	36	29
X	34	40	46	38	35
33	38	43	SAMPLE BLOCK	X	31
26	30	35	35	34	29
	X	34	32	27	

Figure 10 Calorimeter data (cal/cm^2), Shot No. 4097; 10-mil-phenolic removal.

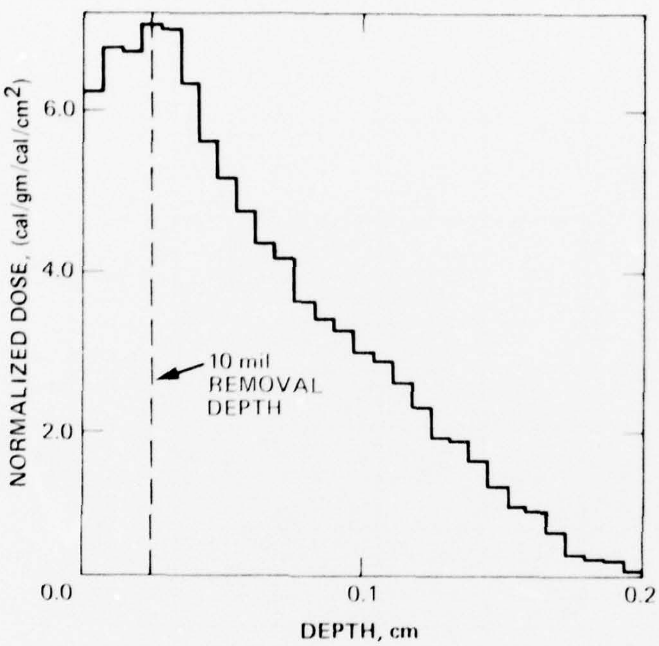

Figure 11 Calculated deposition profile for Shot No. 4097; V = 506 kV, angle = 30 degrees.

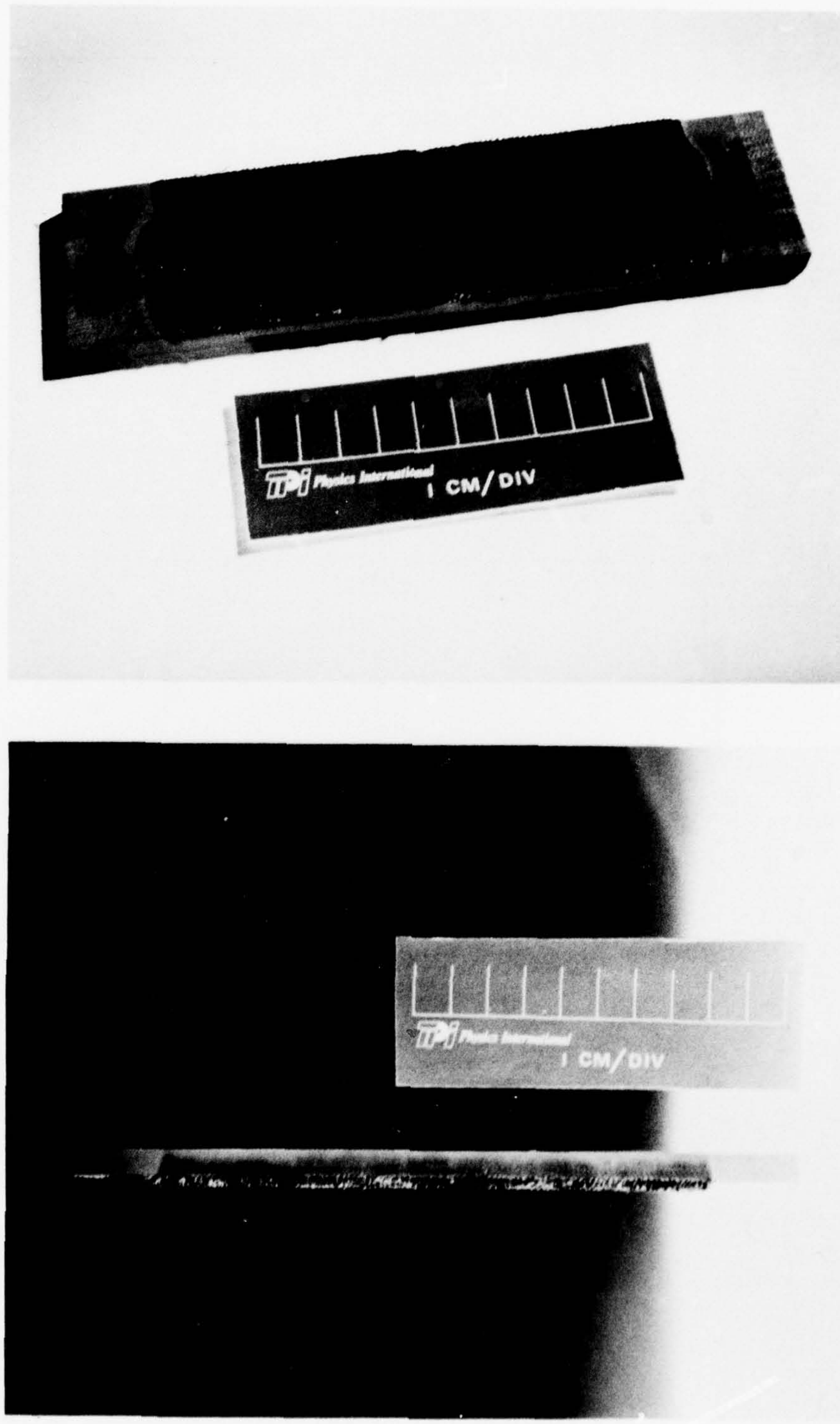

Figure 12 Top and side photos of Shot No. 4097; phenolic removal = 0.010 inch.

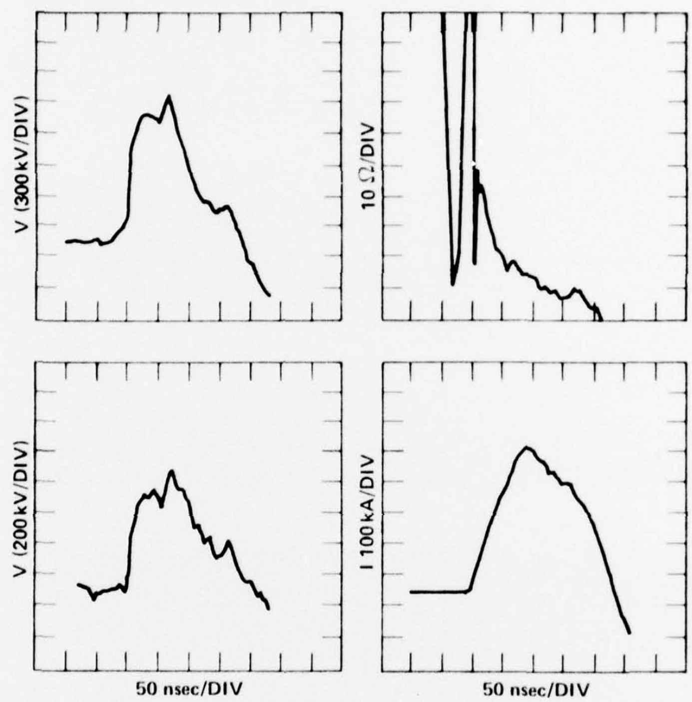

Figure 13 Diode diagnostics for Shot No. 4132; 0.015 inch phenolic removal.

	X	28	X	30	
25	28	27	30	28	30
X	22	28	30	27	26
23	23	25	SAMPLE BLOCK	X	26
21	21	23	25	X	25
	27	27	23	25	

Figure 14 Calorimeter data (cal/cm^2) Shot No. 4131; 15-mil-phenolic removal.

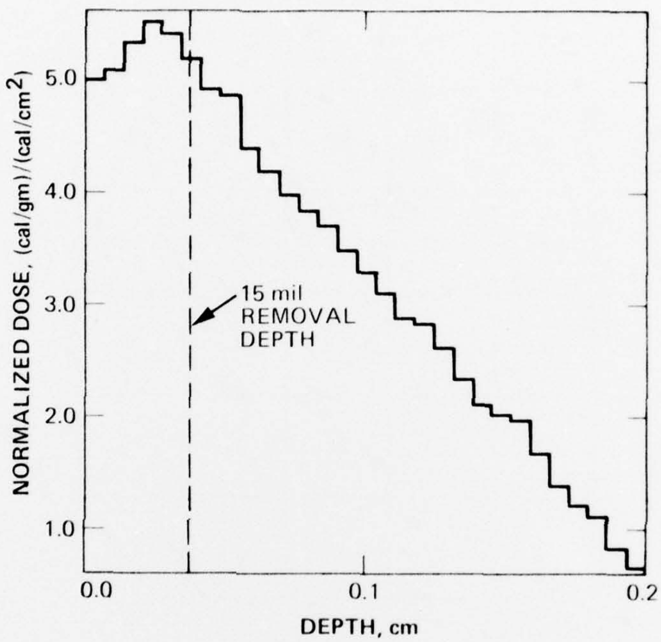

Figure 15 Calculated deposition profile for Shot No. 4132; V = 557 kV, angle = 20 degrees.

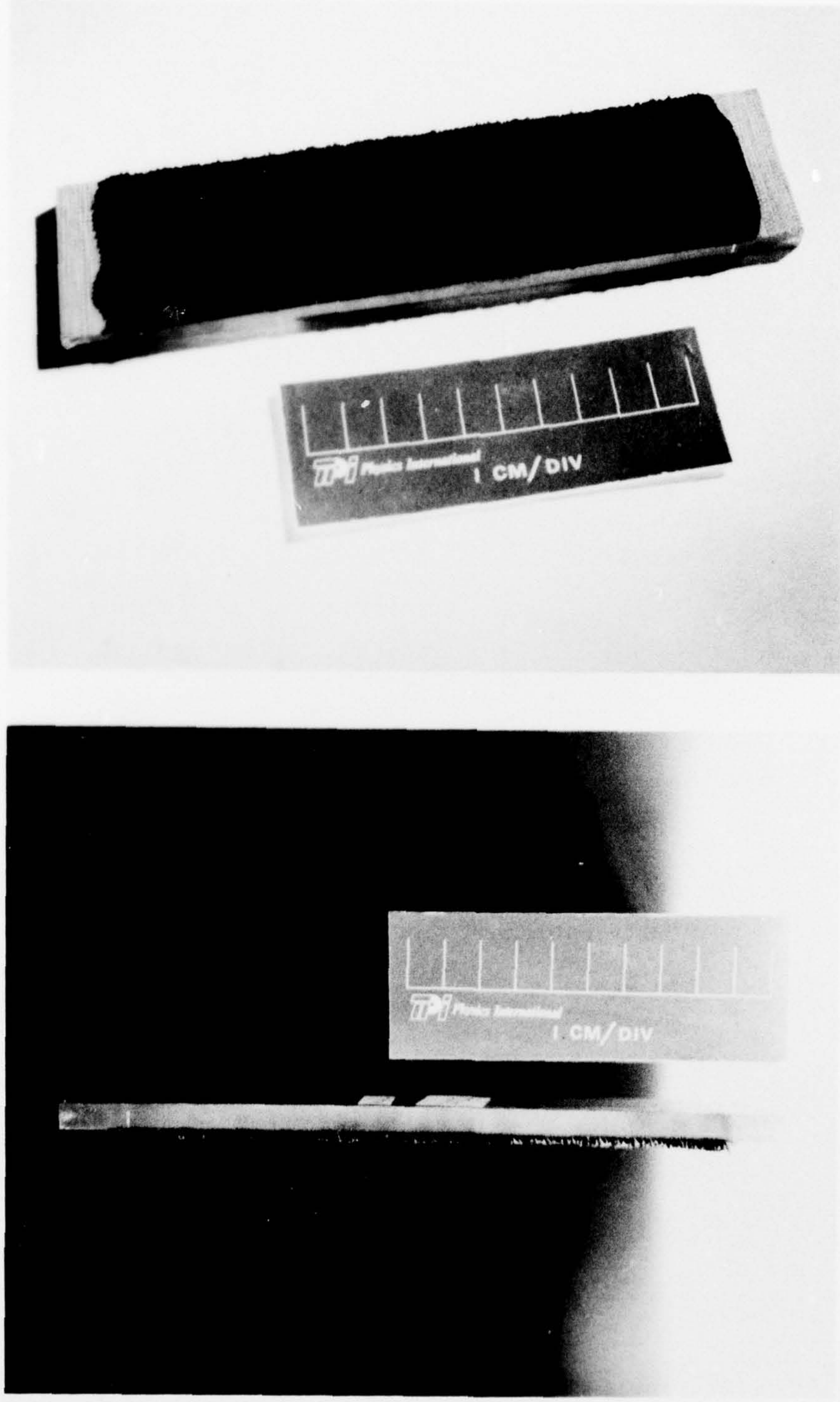

Figure 16   Top and side photos of Shot No. 4132; phenolic removal = 0.015 inch.

Table 2 Depth Removal Record for Each Block

Angle	Phenolic Removal Depth (mils)	Fiber Length (mils)
0°	7-9	100-110
15°	9-10	100-120
30°	5-8	90-110
45°	5-6	60-80
60°	5-7	40-60

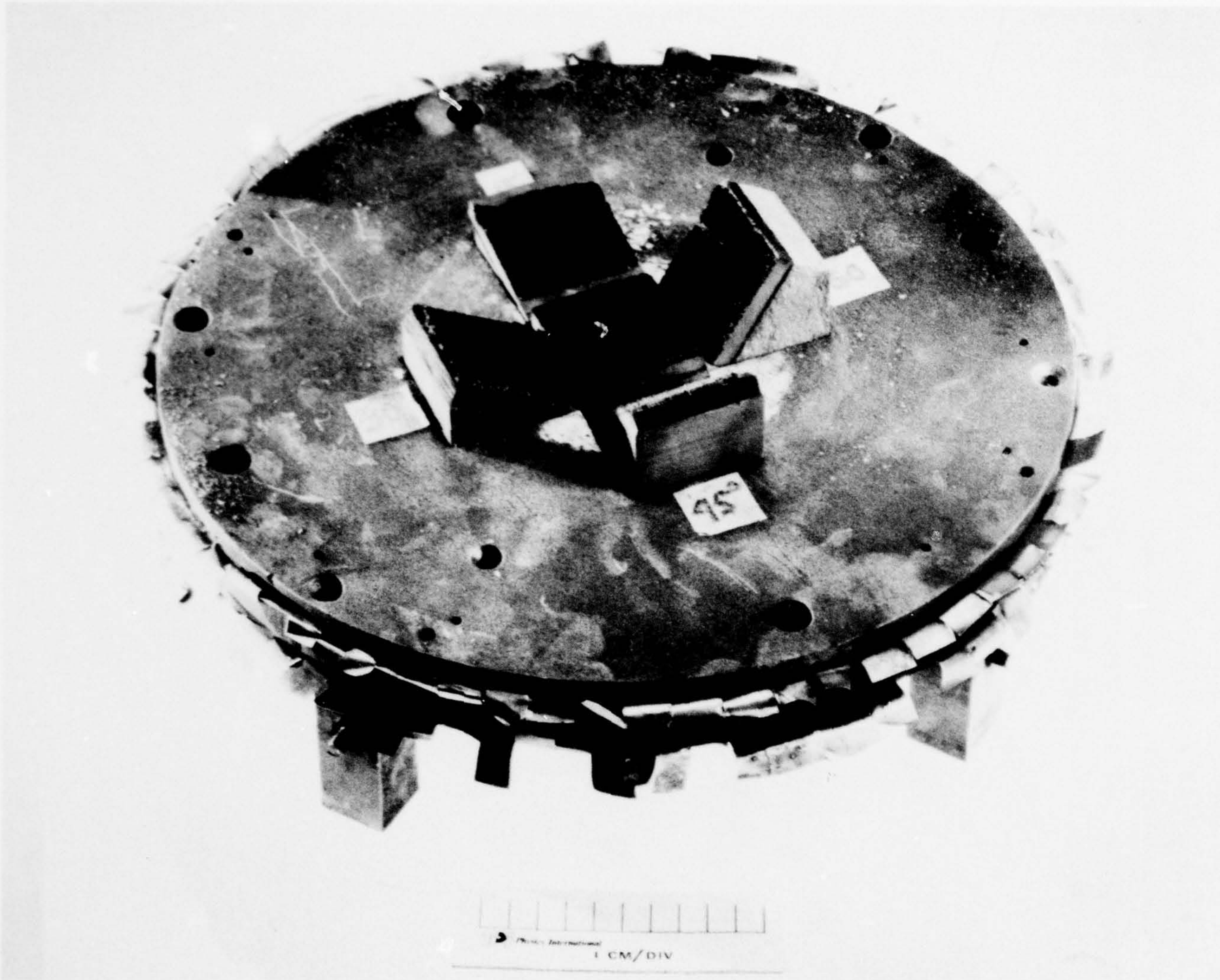

Figure 17 Angle blocks.

45 degrees. The minimum overlap experiment shown in Figure 18 was relatively successful. Because of the gyroradius on a beam when it passes a sharp corner, the mask used on the second shot actually was extended 1 mm into the removal region of the first shot. A slight ridge between the areas of removal resulted. To optimize the smoothness across this region, this overlap should probably be reduced to the order of 1/2 mm.

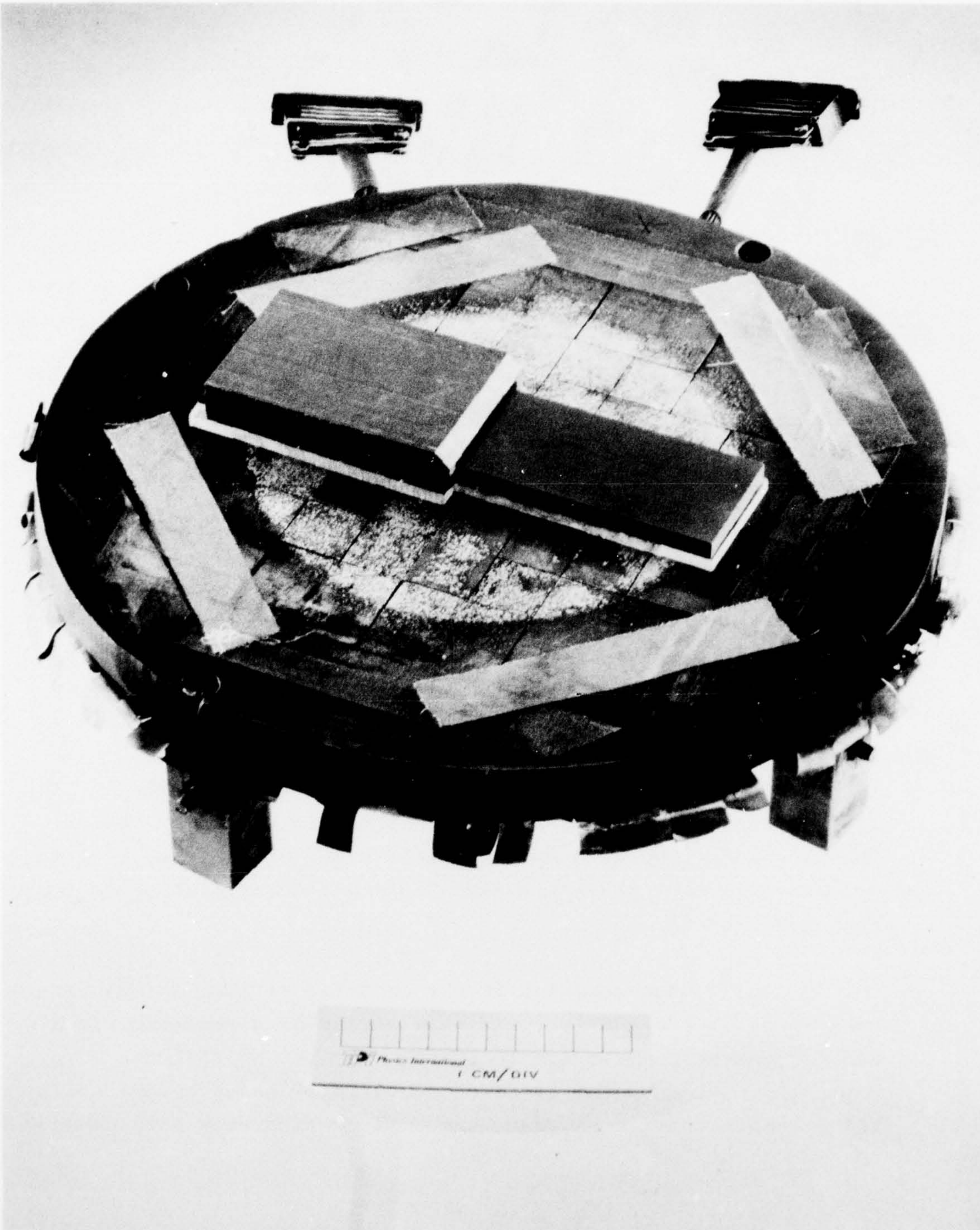

Figure 18   Overlay experiment.

SECTION 5

RECOMMENDATIONS FOR FUTURE EXPERIMENTS

A series of calculations were carried out using the method described in Section 2 to predict the maximum amount of beam area that could be produced on the OWL II or the OWL II' generators. This area, as might be expected, is dependent on the desired removal. For the OWL II generator the maximum beam area is 910 cm^2, 745 cm^2, and 630 cm^2 for 0.13, 0.25, and 0.38 mm of phenolic removal, respectively. Corresponding areas on OWL II' are only slightly larger with 1,080 cm^2, 820 cm^2, and 680 cm^2 for 0.13, 0.25 and 0.38 mm of removal respectively. If a cone with a base diameter of 23 cm and a height of 71 cm is a fair representation of a desired target, this target has a total projected area of approximately 815 cm^2. This implies that with the construction of new hardware it should be possible to use no more than two shots to fully irradiate a given target cone from one side. In fact it is conceivable that a target cone could be irradiated on a single shot for 0.13 or 0.25 mm of removal. This may be pushing the technology since the beam should be larger than the target by some amount on the order of at least 1 cm in all dimensions to allow for variations and uncertainties in the beam edge quality.

A second consideration is the magnetic field. In the present experiment, the magnetic coils have an inside diameter of 40.6 cm and the vacuum chamber has an inside diameter of 35.6 cm. The capacitor bank supplied 64 kJ of electrical energy to the coils. For a target that is between 71 and 74 cm high with a 23-cm-diameter base, either the vacuum chamber must be expanded to a larger diameter to accommodate this target or the target can be slanted at an angle, in which case the uniform magnetic field region must be made longer to keep the beam fluence constant over the entire length of the cone.

To increase the chamber diameter to 74 cm requires a magnetic field energy of approximately 240 kJ. If, instead, a cone is canted at 45 degrees and the chamber diameter is reduced to 58 cm, then the required magnetic field energy is approximately 160 to 170 kJ. Therefore although some gains are made in reducing the magnetic field energy by slanting the cone to a fairly large angle, the effect is much less than a factor of two. A 200 kJ capacitor bank is presently in-house and a reduction of the peak magnetic field by 10 percent would allow the use of this capacitor bank and a full 74 cm vacuum chamber.

Therefore we see that the number of shots used to irradiate a single conical target can be reduced to two or possibly one for very low removal depths and the target can be used at canted angles between 0 and 45 degrees. It is also possible to use a number of shots of the order of 7 to 10 and regulate a cone in the present geometry. Firm recommendation on the direction to proceed must await a very clear definition of the goals of the next step and in particular if the target can be cut into a number of pieces or if it should remain in a single piece.

SECTION 6

CONCLUSIONS

In conclusion, the ability to control the depth of phenolic removal in a carbon phenolic material has been demonstrated between 0.1 and 0.4 mm. A series of samples has been generated that can now be used for further testing. The reproducibility appears adequate for testing future samples and sufficient machine energy exists to substantially increase the beam area if desirable.

REFERENCES

1. K. Childers and C. Stallings, "OWL II Diode Study," DNA 4432F, Defense Nuclear Agency, Washington, D.C., (1977).

2. B. Alder, et al., Methods in Computational Physics, Vol. 1, Academic Press, New York, N.Y. (1963).

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